

FELDSPAR-PROVENANCE DATES IN A STRATIGRAPHIC SECTION OF TILL IN GAHANNA, OHIO¹

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ABSTRACT. The internal layering and provenance of feldspar in 3 tills and in one outwash deposit at Gahanna, Ohio, were studied by determining pebble lithologies and Rb-Sr dates of feldspar. Variations in lithology of pebbles and in the Rb-Sr ratios of feldspar in the 125–250 micrometer fractions reveal discontinuities which divide the upper 2 tills into 2 subunits each. Each of the lower subunits appears to be more homogeneous than the upper ones based on comparisons of standard deviations. This suggests the lower subunits may be basal or lodgement till and the upper subunits may be ablation till. Feldspar-provenance dates in till of the midwestern United States are expressions of the proportion of mixing of feldspar grains originating from the Superior (2.7 b. y.) and Grenville (1.07 b. y.) structural provinces of the Canadian Precambrian Shield. The Rb-Sr dates of feldspar in the layers of till and outwash of the Gahanna section are so variable that average dates cannot be used to distinguish among them. The lack of systematic stratigraphic variation of provenance dates indicates the feldspars are heterogeneous mixtures of the two Precambrian components. Approximately 90% of the dates have values between 1.0 and 1.5 b. y., which demonstrates the dominance of feldspar derived from the Grenville Province. Four samples whose dates are less than 1.0 b. y. contain younger feldspar presumably derived from sandstone of late Paleozoic age.

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INTRODUCTION

Studies dealing with provenance and internal layering of till can provide information about the geologic and climatic history of the Pleistocene epoch. Techniques used to determine provenance of glacial sediment have been reviewed by Raukas et al. (1978) and Dreimanis (1971). Taylor and Faure (1979) used isotopic dating and obtained an average date of 496 million years by the Rb-Sr method for the <62 micrometer fraction of till from the Powell-Union City Moraine in Ohio. This date does not indicate the age of deposition but results from the presence of locally derived sediment from rocks of Paleozoic age in the silt and clay fraction of the till. The Taylor and Faure (1979) study

revealed feldspar is present in appreciable amounts in Late Wisconsinan till and over 30% of it is concentrated in the 125–250 micrometer fraction. In another study, Taylor and Faure (1981) showed this feldspar is a mixture of grains derived from the Superior structural province (2.70 b. y.) and the Grenville structural province (1.07 b. y.) of the Canadian Precambrian Shield. The provenance dates, calculated from $^{87}\text{Sr}/^{86}\text{Sr}$ and Rb-Sr ratios of feldspar, increase from 1.2 b. y. in the east to 1.8 b. y. in the west along the Powell-Union City Moraine of Ohio. The increase of the dates is attributable to a higher proportion of feldspar derived from the Superior Province in the western part of the moraine.

The objectives of the present study are:

- 1) To determine whether tills can be subdivided internally on the basis of

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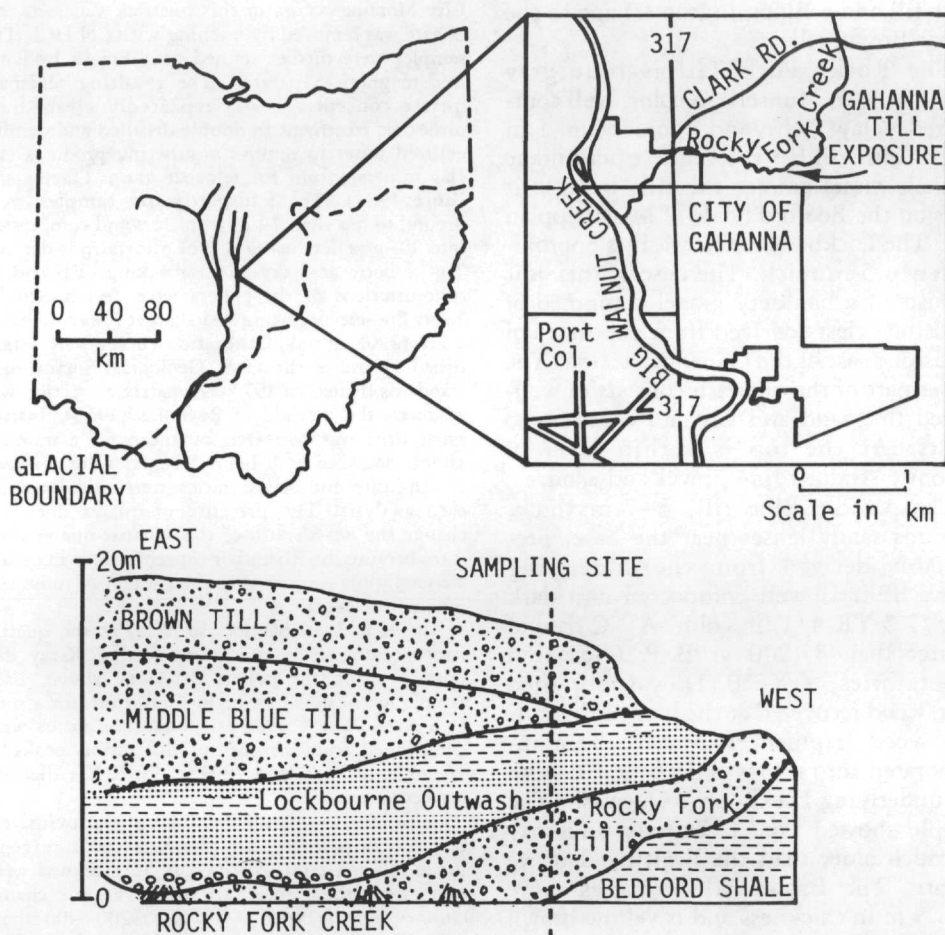


FIGURE 1. Location of collecting site and stratigraphic section of till and outwash deposits on Rocky Fork Creek at Gahanna, Ohio (Goldthwait 1965).

Rb-Sr provenance dates of feldspar and by the lithologic composition of clasts, 2) To interpret the observed internal variation of these parameters in terms of the transport of sediment by ice, and 3) To explain differences in the provenance dates of feldspar of tills as evidence of changes in ice flow direction during the Wisconsin glacial.

Samples were taken from a section of Wisconsin tills exposed along Rocky Fork Creek at Gahanna, Ohio. The exposure was described by Goldthwait (1965) and is shown in figure 1. The sampled section is 18 m thick and consists of 3 tills and one outwash. The lowest till is the

Rocky Fork Till which is overlain by the Lockbourne Outwash and by the Darby Drift which is subdivided into the Middle Blue till and the overlying Brown till (fig. 1). Goldthwait (1965) reported a radiocarbon date of $46,600 \pm 2000$ years B. P. (Isotope Physics Lab, Groningen Netherlands, GrN-3219) from the upper part of the Lockbourne Outwash and used it, as well as other evidence, to suggest that the outwash and the Rocky Fork till are of early Wisconsin (Altonian) age. He also reported a date of $23,000 \pm 850$ years B. P. (Goldthwait 1965) from the Middle Blue till and assigned a late Wisconsin (Shelbyville) age to the Middle

Blue till and a Bloomington (?) age to the upper Brown till.

The Rocky Fork Till is blue gray (2.5 YR 5/0, Munsell) in color, well compacted, clay rich, and more than 1 m thick. This till has the highest percentage of shale clasts among the tills because it rests on the Bedford Shale of Mississippian age. The Lockbourne Outwash is approximately 4.5 m thick. The base of this unit consists of a bouldery gravel composed of sandstone clasts derived from exposures of sandstone east of the Gahanna section. The upper part of the outwash consists of well-sorted fine sand and silt and contains no clasts. At the top is a thin layer of limonite-strained fine gravel and sand.

The Middle Blue till, 3–7 m thick, contains sandy lenses near the base, presumably derived from the underlying outwash. It is well compacted and dark gray (7.5 YR 4/1) in color. A ^{14}C date of greater than 37,000 yr B.P. (Geochron Laboratories, GX-7031) was obtained from wood recovered at the base of this till. The wood fragment may have been incorporated into the Middle Blue till from the underlying Lockbourne Outwash. The sample showed no ^{14}C activity and may be much older than the limiting date we report. The Brown till averages more than 5 m in thickness and is yellow brown (10 YR 5/4) in color. This layer contains a discontinuous sandstone boulder pavement exposed along the eastern wall of the section that was not present at our sampling site.

METHODS AND MATERIALS

Samples weighing approximately 5 kg were collected at 30-cm intervals beginning in the Rocky Fork Till and extending close to the top of the Brown till. The part of the outwash consisting of cobble and boulder-sized local sandstone was not sampled. The silt and clay-sized fractions (<62.5 micrometers) were removed by suspension in water (Pettyjohn 1975). The coarse fraction was dried and the pebbles (>4 mm) were divided into 4 lithologic categories: sandstone, shale, carbonates, and igneous-metamorphic rocks. The fine-sand fraction (125–250 micrometers) was selected for analysis of feldspar. Taylor and Faure (1979) reported 32% of the feldspar in till from the Powell-Union

City Moraine occurs in this fraction. Calcium carbonate was removed by leaching with 2N HCl. The samples were further refined on a Frantz Isodynamic magnetic separator. The resulting feldspar-quartz concentrate was repeatedly cleaned by ultrasonic treatment in double distilled and demineralized water to remove weathering products and clay minerals from the feldspar grains (Taylor and Faure 1981). The feldspar-quartz samples were ground to less than 74 micrometers and compressed into 10-g pellets using 3 g of mineral powder and 7 g of boric acid crystals as backing. Rb and Sr concentrations of the pellets were determined by X-ray fluorescence using a Mo-target X-ray tube and a LiF (220) crystal. Calibration curves were established by use of the U. S. Geological Survey rock standards (Flanagan 1973). A matrix correction was made by the method of Reynolds (1963). Instrument drift was corrected by means of a monitor sample analyzed each hour. Samples were analyzed in triplicate and Rb-Sr ratios were calculated for each analysis. The presence of quartz does not change the Rb-Sr ratio of the feldspar-quartz mixtures because the Rb and Sr concentrations in quartz are negligible compared to the content of those elements in feldspar.

The K-feldspar-plagioclase ratios of the quartz-feldspar samples were determined by X-ray diffraction using the pellets described above. Each sample was scanned twice in 4 positions for a total of 8 scans. The K-feldspar-plagioclase ratios were determined from heights of diffraction peaks at 2θ angles of 27.5° and 28.0° of Cu-K X-radiation, respectively.

Solutions were prepared using approximately 0.5 g of the powdered samples dissolved in reagent-grade HF and triple-distilled H_2SO_4 . Sr was separated from these solutions using cation-exchange chromatography with AGWX-8, 200–400 mesh resin. The isotopic composition of Sr was determined on a Nuclide Corp. solid-source mass spectrometer. All measured $^{87}\text{Sr}/^{86}\text{Sr}$ ratios were corrected for isotope fractionation to a standard value of 0.1194 for the $^{86}\text{Sr}/^{88}\text{Sr}$ ratio. The Eimer and Amend SrCO_3 isotope standard was analyzed twice during the course of this study and has an average $^{87}\text{Sr}/^{86}\text{Sr}$ ratio of 0.70818. This ratio is in agreement with the accepted value of this standard.

RESULTS AND DISCUSSION

Tills can be divided into 2 types whose origin depends on the way in which the sediment is transported by the ice (Dreimanis 1978). Supraglacial till is defined as sediment that is carried on the glacier surface or in the ice. It is characterized by angular rock fragments produced by frost shattering and a high proportion of coarse sediments that remain after washing

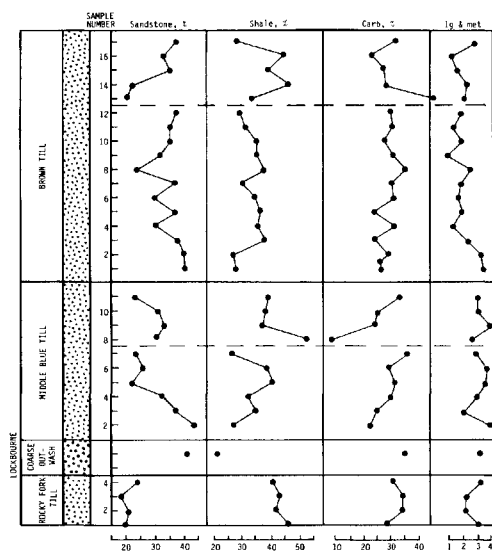


FIGURE 2. Stratigraphic variations of pebble lithologies (>4000 micrometers) in glacial deposits at Gahanna, Ohio. The long dashed lines represent discontinuities.

(Drake 1971, Dreimanis 1978). Basal till (Dreimanis 1971) also called lodgement till by Flint (1971) is composed of sediment and clasts that have been entrained and abraded at the base of the ice. It is more compact than ablation till, possesses more strongly aligned pebble fabrics, and contains a higher abundance of flattened unweathered striated clasts. It may also contain evidence of basal shear planes and is generally less washed. Drake (1971) used fabric, mechanical analyses, shape, degree of weathering, presence of striations, and pebble lithology to differentiate between lodgement and ablation till in New Hampshire. We have used pebble lithology and the following parameters in an attempt to distinguish lodgement till from ablation till: K-feldspar-plagioclase ratios, Rb-Sr ratios, and Rb-Sr dates of feldspar.

PEBBLE LITHOLOGIES. The comparison of pebble counts and patterns they form when plotted upsection provides information regarding the internal layering of till. Lodgement till should contain the highest proportion of clasts derived from bedrock directly beneath the base of the

glacier. Ablation till, on the other hand, carries drift from greater distances up-ice as well as locally derived material. Therefore, it might be expected that more lithologic variety and different proportions of lithologic types exist in ablation till than in lodgement till.

The lithologies in the Rocky Fork Till (fig. 2) show no discontinuities and are relatively homogeneous. The shale content of this layer decreases from 47.1% at the bottom to 40.7% at the top. Sandstone and carbonate percentages are $20.8 \pm 2.4\%$ and $32.1 \pm 2.7\%$, respectively. Igneous and metamorphic rocks make up $2.8 \pm 0.5\%$ of the clasts (table 1). The overlying sandy outwash contains no clasts. The gravel layer at the top of the Lockbourne Outwash contains 40.8% locally derived sandstone but its shale content is only 20.1%. In the Middle Blue till, the abundance of sandstone clasts decreases from 44.1% at the base to 23.7% in sample 7, about 1.8 m above the top of the Lockbourne Outwash (fig. 2). The concentrations of shale and carbonate clasts generally increase in the same interval whereas the abundance of igneous and metamorphic clasts range from 2.2 to 3.9% and average $3.2 \pm 0.6\%$. The base of the Middle Blue till is characterized by the presence of sand lenses. The upper part (1.2 m, samples 8–11) lacks the patterns of pebble lithologies found below. The concentrations are: sandstone = $30.0 \pm 4.3\%$, shale = $42.3 \pm 7.9\%$, carbonate = $23.3 \pm 10.3\%$, and igneous-metamorphic = $3.2 \pm 0.7\%$. The upper subunit contains less than $\frac{1}{4}$ as much sand as the basal unit. On the basis of these data, we place a discontinuity between samples 7 and 8 in the Middle Blue till as shown in figure 2.

We place a similar discontinuity between samples 12 and 13 in the Brown till. Pebble lithologies of the lower subunit (samples 1–12, 3.4 m) are more uniform than those in the upper portion of this till (samples 13–17, more than 1.5 m) and contain $35.2 \pm 4.7\%$ sandstone. Sandstone pebble concentrations of the upper

TABLE 1

Summary of mineralogical, chemical and isotopic parameters of glacial deposits at Gabanna, Ohio.

Unit	Thickness m	No. of Samples	SS %	Pebble Lithology		Ig. & Met. %	Feldspar	
				Shale %	Carb %		Rb/Sr	Date b.y.
Brown Till								
Upper	1.5	6	29.8	38.5	30.2	2.1	0.216	1.14
			± 7.7	± 7.8	± 8.9	± 0.5	± 0.029	± 0.15
Lower	3.6	12	35.2	33.1	29.4	2.0	0.211	1.23
			± 4.7	± 3.2	± 3.1	± 0.8	± 0.012	± 0.17
Middle Blue Till								
Upper	1.2	4	30.0	42.3	23.3	3.2	0.216	1.17
			± 4.3	± 7.9	± 10.3	± 0.7	± 0.024	± 0.19
Lower	1.8	6	31.2	33.7	29.3	3.2	0.205	1.23
			± 8.5	± 6.1	± 4.8	± 0.6	± 0.012	± 0.09
Lockbourne Outwash								
Coarse (upper)	0.3	1	40.8	20.1	35.1	3.3	0.18	1.47
			—	—	—	—	—	—
Rocky Fork Till								
	1.2	4	20.8	43.5	32.1	2.8	0.182	1.38
			± 2.4	± 2.6	± 2.7	± 0.5	± 0.002	± 0.07

subunit (samples 13–17) increase upward from 22.8% to 37.4% and have a mean of $29.8 \pm 7.7\%$. Stratigraphic variations of this parameter support placement of a discontinuity between samples 12 and 13. Average values of other parameters are listed in table 1. Internal layering of till is displayed also by the range of variation of pebble lithologies in the subunits. The upper subunit of the Brown till is more heterogeneous than the basal unit, as indicated in table 1. Standard deviations of the sandstone, shale, and carbonate concentrations of the upper subunit are all greater than those of the basal unit by more than a factor of two on the average. Systematic trends and discontinuities in pebble lithologies in the 2 tills and differences in homogeneity of top and bottom subunits are consistent with the assumption that the lower subunit is lodgement till and that the upper is ablation till.

K-FELDSPAR-PLAGIOCLASE AND Rb-Sr RATIOS OF FELDSPAR. The K-feldspar-plagioclase ratios of the feldspar in the 125–250 micrometer fractions were measured to determine whether they vary systematically within the subunits defined by pebble lithologies. These ratios ranged

from 0.31 to 1.22; but average values for all subunits are identical within analytical error (sandy outwash: 0.64 ± 0.26 ; basal subunit of Middle Blue till: 0.88 ± 0.46 ; upper subunit of Middle Blue till: 0.63 ± 0.13 ; and basal subunit of Brown till: 0.59 ± 0.14). The upper subunit of the Brown till was not analyzed when it became apparent that this parameter is not useful for studying internal layering of these till sheets.

The Rb-Sr ratios of feldspar in the 125–250 micrometer fractions of the tills and of the outwash vary from 0.18 to 0.36. The Rocky Fork till has an average of 0.182 ± 0.002 . The fine sand and silt outwash above it has a higher ratio and shows a systematic increase from 0.27 at the base to 0.36 at the top. One sample has an anomalously high Rb-Sr ratio of 0.45. This feldspar also has a high $^{87}\text{Sr}/^{86}\text{Sr}$ ratio of 0.7205 and yields a comparatively low provenance date of 0.88 billion years (b. y.). A possible explanation for this discrepancy is suggested later in this report based on the presence of feldspar derived from Mississippian sandstones. The increase of Rb-Sr ratios up-section may reflect changes in the sedimentological

regime of the outwash. However, no positive correlation between the Rb-Sr ratio and the K-feldspar-plagioclase ratio was observed.

The Rb-Sr ratios of the basal till of the Middle Blue are relatively constant with an average of 0.205 ± 0.012 . The upper subunit is more heterogeneous with an average of 0.216 ± 0.024 . Likewise, in the Brown till, there is an average ratio of 0.211 ± 0.012 for the basal till and 0.216 ± 0.029 in the ablation till (table 1). In each case, the Rb-Sr ratios of the feldspar in the upper subunits have larger standard deviations than those of the lower subunits. This is in accord with the ablation and lodgement till hypothesis.

FELDSPAR-PROVENANCE DATES. Studies by Gross and Moran (1972) and Taylor and Faure (1979) indicate feldspar is an abundant constituent of Late Wisconsinan till in Ohio. Most of the feldspar originated from the Canadian Shield and is a mixture of grains from the Grenville and Superior structural provinces. The bedrock of Ohio consists of sedimentary rocks of Paleozoic

age that contain little if any feldspar (Taylor and Faure 1981). Therefore, the Rb-Sr dates of feldspar in these tills should fall between 1.07 b. y. and 2.70 b. y. The provenance date represents the proportion of mixing of these feldspar grains and is not the age of the feldspar or the age of the till.

One of the objectives of this study is to examine provenance dates in the context of a stratigraphic section of till. If tills have different provenances, they may contain different mixtures of feldspar grains and may therefore yield different average provenance dates. In addition, feldspar from the 2 source regions may be mixed in different proportions in basal and ablation till causing them to have different average provenance dates. Provenance dates of feldspar are not affected by post-depositional alteration of till because: 1) Feldspar has excellent retentivity for radiogenic ^{87}Sr (Faure 1977); 2) Adhering particles of clay minerals and oxides were removed from feldspar grains by ultrasonics prior to analysis; 3) Alteration of till is very slight as indicated by the presence of unstable components such as wood fragments, magnetite, and fragments of concretionary marcasite derived from the underlying bedrock.

The feldspar provenance dates for the Rocky Fork Till are relatively homogeneous with a range of 1.31 b. y. to 1.44 b. y. The average date is 1.38 ± 0.07 b. y. (table 1, fig. 3). The dates in the sandy part of the Lockbourne Outwash range from 0.88 b. y. to 1.15 b. y. and have a mean of 1.02 ± 0.10 b. y. Feldspar from the coarse layer at the top yielded a date of 1.47 b. y. The dates for 5 of the 7 samples from outwash are less than the Grenville Province date of 1.07 b. y. This suggests a third and younger feldspar component is present which may have originated from the sandstone detritus that is abundant in the outwash. Taylor and Faure (1981) considered the possibility of contamination of till by feldspar grains from arkosic sandstone of late-Paleozoic bedrock in eastern

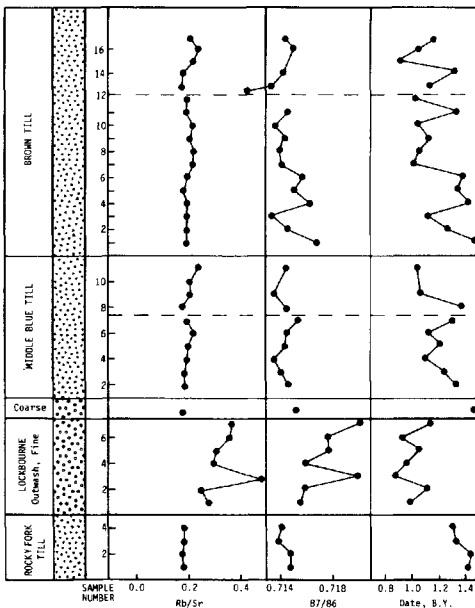


FIGURE 3. Stratigraphic variation of Rb/Sr ratios and provenance dates of feldspar (125–250 micrometers) in glacial deposits at Gahanna, Ohio.

Ohio. Feldspar from Mississippian sandstone near Mansfield, Ohio, yielded a Rb-Sr date of 500 ± 20 m. y. The presence of feldspar from such sandstones significantly lowers the provenance date of till and its presence should therefore be considered in the interpretation of these dates.

The Middle Blue till has dates ranging from 1.04 b. y. to 1.38 b. y. (fig. 3). The average for the entire layer is 1.21 ± 0.12 b. y. The mean provenance date for the lower subunit of this till is 1.23 ± 0.09 b. y., whereas that of the upper subunit is 1.17 ± 0.19 b. y. (table 1). The average dates are statistically indistinguishable but the range of values exceeds analytical errors and suggests the feldspar is not a homogeneous mixture of grains

derived from the source regions on the Canadian Shield. The most striking feature of this layer is the systematic trend in pebble lithologies, Rb-Sr ratios and provenance dates of feldspar in the basal subunit (figs. 2, 3). The patterns of decreasing dates and increasing Rb-Sr ratios up-section displayed by sample 1 of the coarse outwash and samples 2, 3, and 4 of the Middle Blue till suggests mixing has occurred at the base of the glacier that deposited this till. Mixing may be caused by basal drag (Sugden and John 1976) which involves shearing over successive layers of ice-carried sediment. The mixing at the base of the Middle Blue till and the presence of sand lenses are therefore attributable to basal drag.

The feldspar provenance dates of the Brown till have a bimodal distribution shown in fig. 4. They range from 0.94 b. y. to 1.49 b. y. and have a mean of 1.20 ± 0.16 b. y. The average for the lower subunit is 1.23 ± 0.17 b. y. and for the upper subunit the average is 1.14 ± 0.15 b. y. These averages are indistinguishable and mask the real variations in provenance dates that exist in this layer. For example, samples 4, 5 and 6 (fig. 3) yield a date of 1.39 ± 0.04 b. y. whereas samples 7, 8, 9 and 10 average only 1.08 ± 0.04 b. y. The difference indicates feldspar in the Brown till is not a homogeneous mixture of grains derived from the two sources regions on the Canadian Shield. There are no systematic differences among the average provenance dates of the tills at this locality nor are there systematic variations within a given till. Instead, the provenance dates vary unsystematically and thereby imply tills are heterogeneous with respect to feldspar provenance dates.

The average provenance dates of the till layers exposed at Gahanna are significantly lower than those of the Scioto sublobe of the Powell-Union City Moraine in north-central Ohio for which Taylor and Faure (1981) reported an average of 1.54 ± 0.06 b. y. (1σ). The difference indicates the till of the Powell-Union City

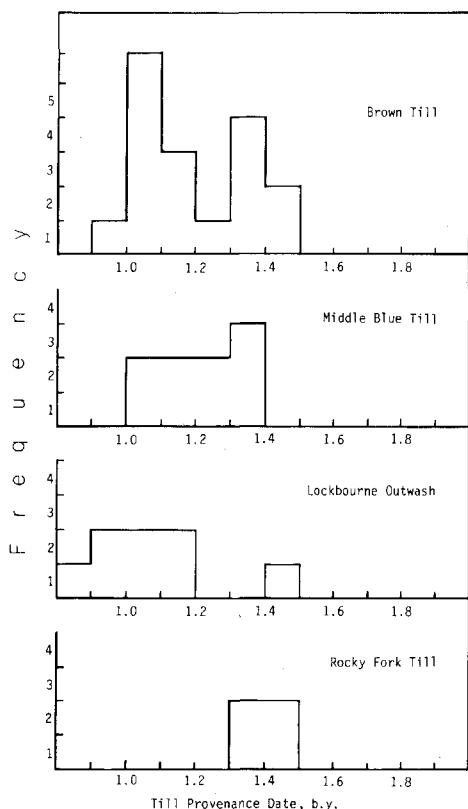


FIGURE 4. Histograms of Rb-Sr dates of feldspar in 125-250 micrometer fractions of till and outwash at Gahanna, Ohio.

Moraine, which is probably younger than the Brown till at Gahanna, contains a larger fraction of feldspar derived from the Superior Province. The greater abundance of feldspar from this provenance implies a greater influence of the Huron lobe in the ice sheet that deposited the Powell-Union City Moraine about 14,000 years B. P.

The Rocky Fork Till appears to be composed only of basal till judging from the homogeneity of all parameters considered in this study. The absence of ablation till suggests it was eroded and the contact between the Rocky Fork till and the overlying Lockbourne Outwash is a disconformity.

The base of the Blue till contains sand lenses probably derived from the underlying outwash by basal drag of the ice sheet. The systematic mixing relationships displayed by pebble lithologies and provenance dates suggest the outwash was not frozen when it was overridden by the ice and this till layer may have been deposited by a wet-based glacier. The presence of this mixed bottom layer is characteristic of the Middle Blue till but not of the Brown till.

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PAPER OF THE YEAR

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